Electroweak Physics at the Tevatron

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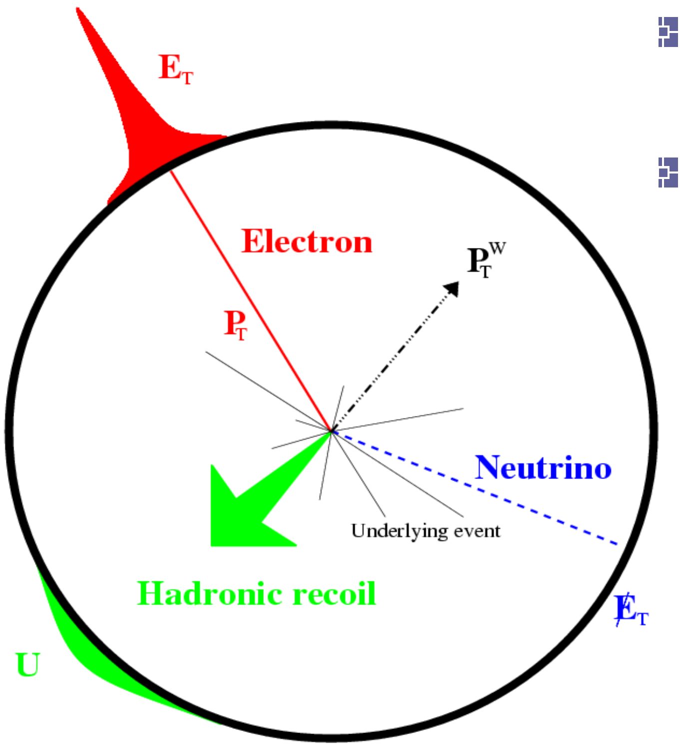
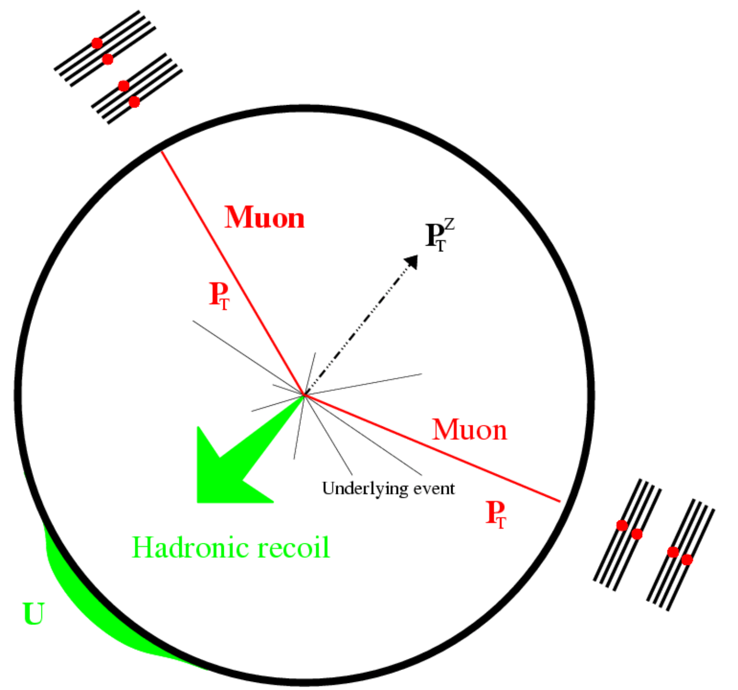
Outline

- Goals of Tevatron Electroweak Physics program
- Status of Run 2 and Preliminary Run 2 Results
- Future Outlook

W and Z Production

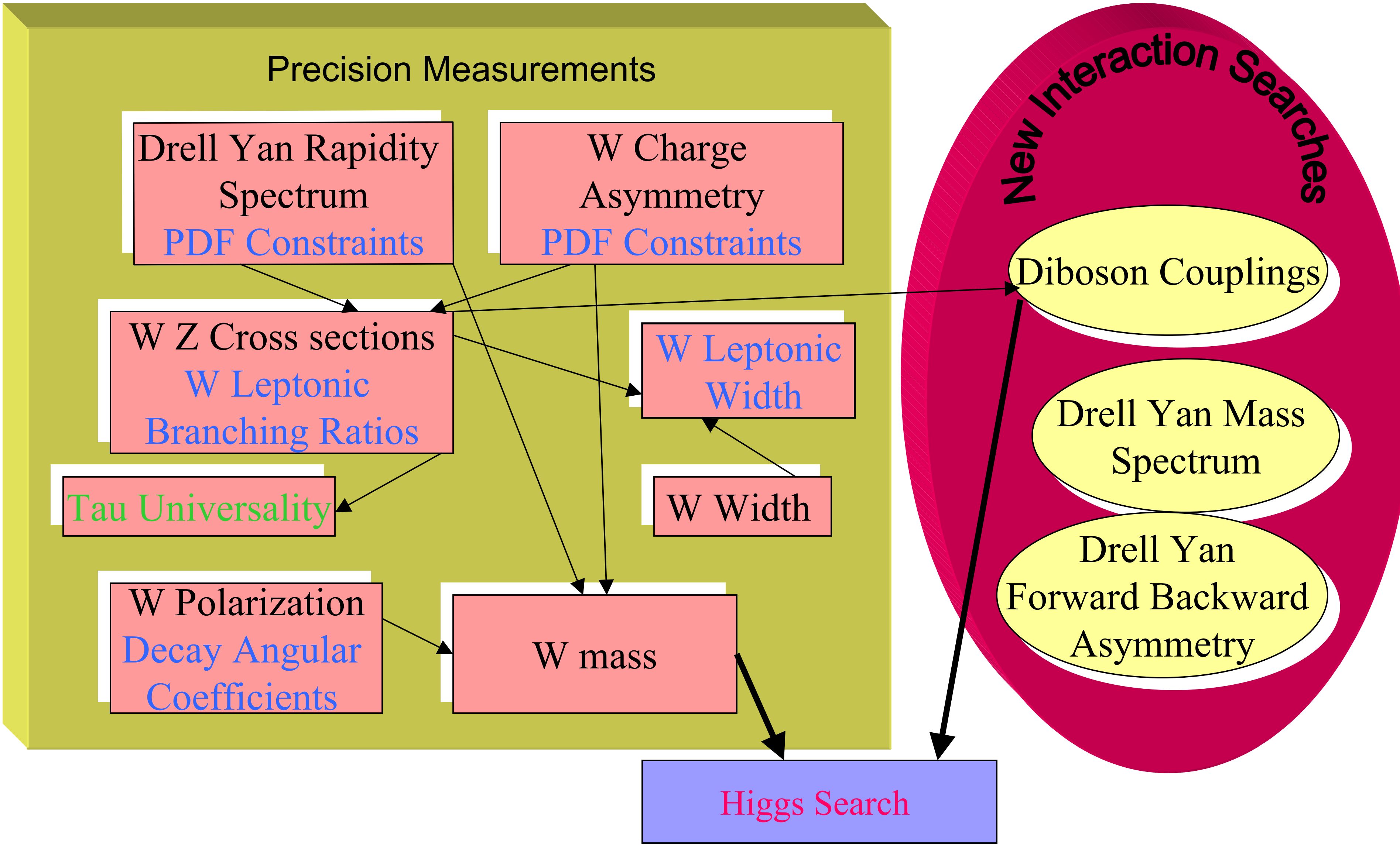
- **Clean W and Z production signatures:**
  - W: Isolated, high pt lepton with missing transverse momentum
  - Z: two isolated leptons





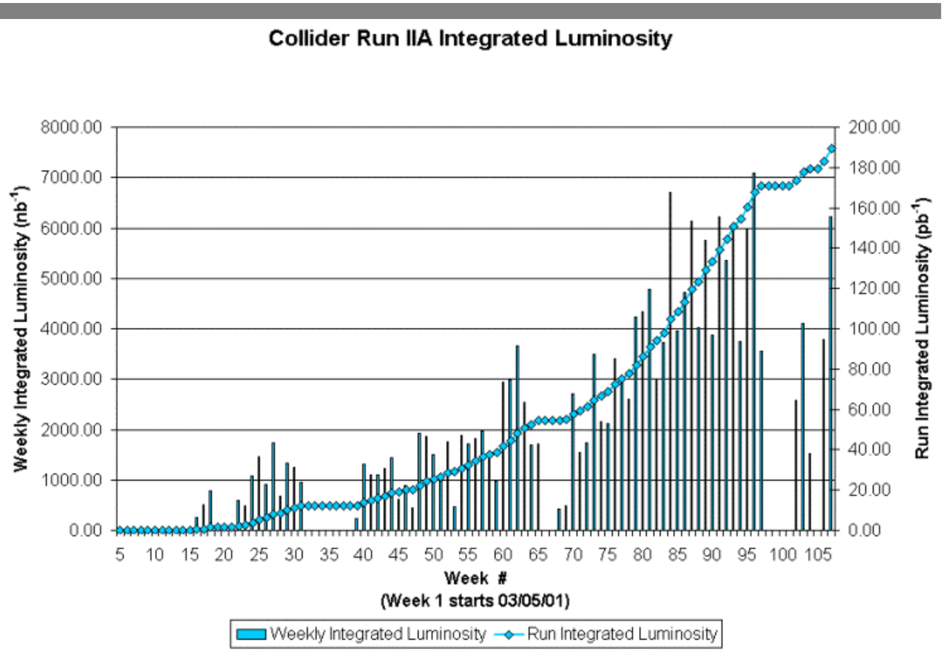
- Typically small hadronic recoil

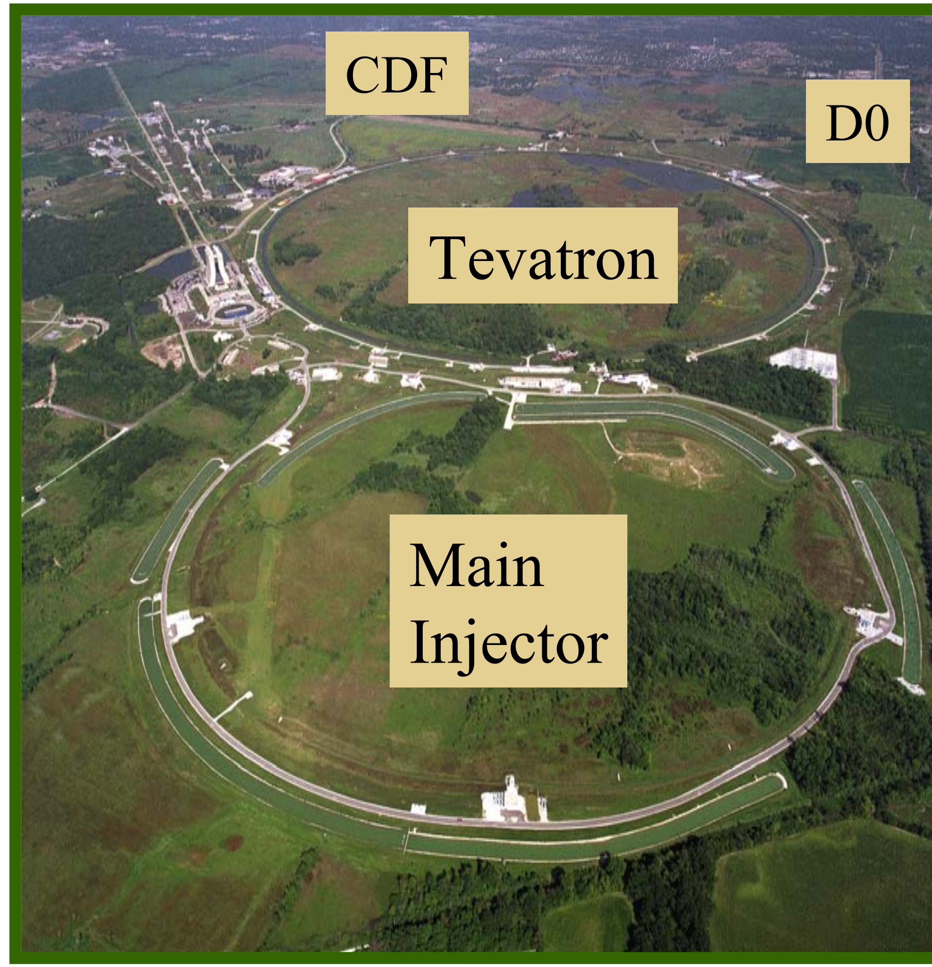
Electroweak Physics Roadmap



Tevatron Run 2

- Main Injector and Tevatron delivering luminosity at 1.96 TeV

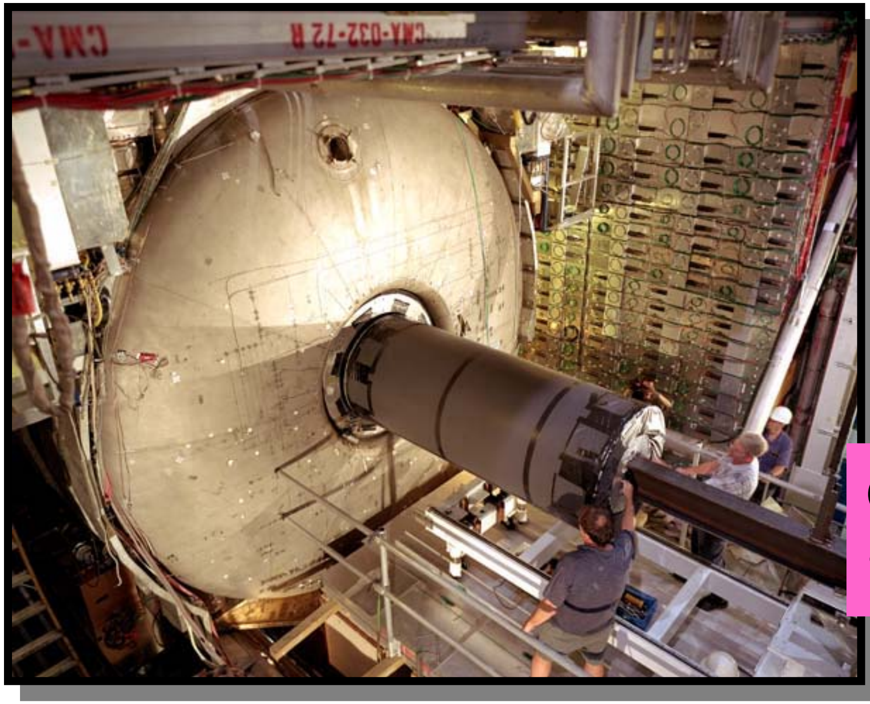


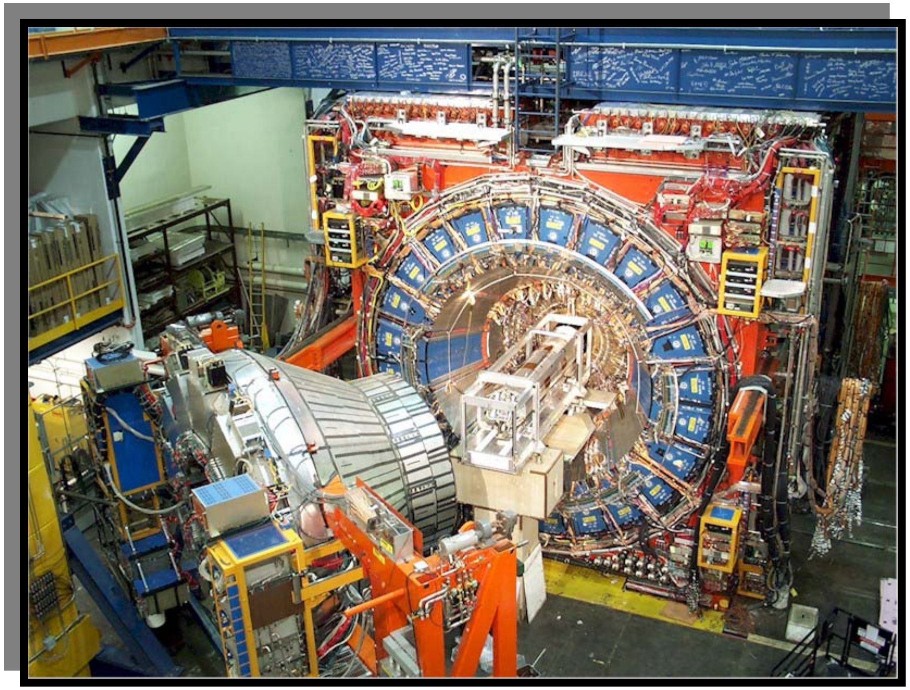


Upgraded CDF and D0 Detectors

Upgraded Muon systems, readout and trigger electronics

D0: new Solenoid, Fiber Tracker, Silicon Detector

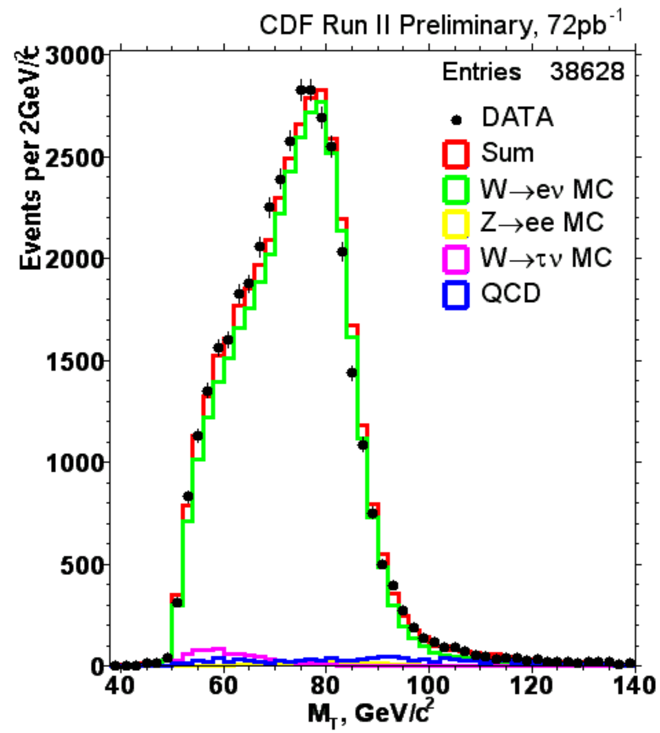


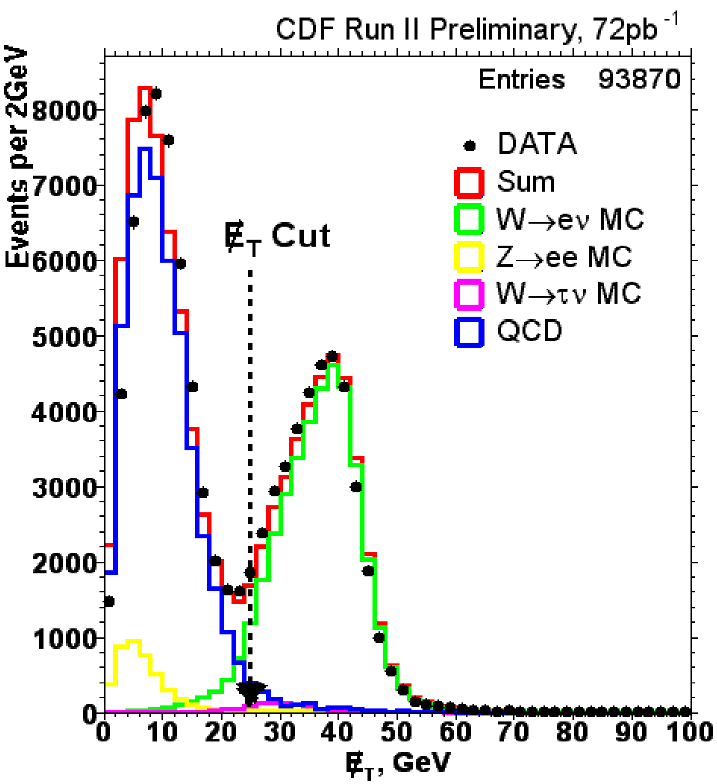


CDF: new Central Drift Chamber, Silicon Detector and Plug Calorimetry

W and Z Cross Sections

- Establish baseline measurements for understanding detectors
- Very useful as luminosity monitor, can be used to normalize other hard-scattering cross sections





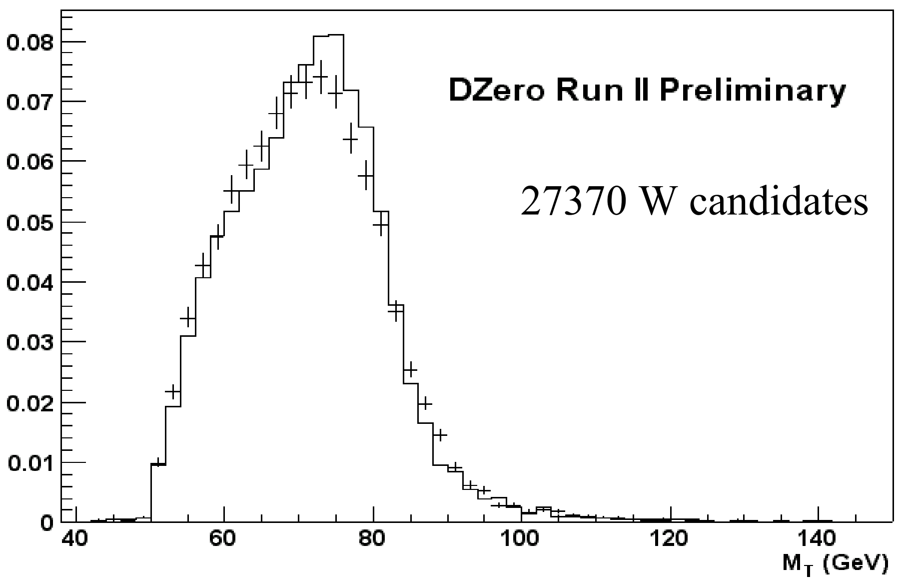
$$\sigma.B(W \to e\nu) =$$
$$2.64 \pm 0.01_{stat} \pm 0.09_{sys} \pm 0.16_{lum}\ nb$$

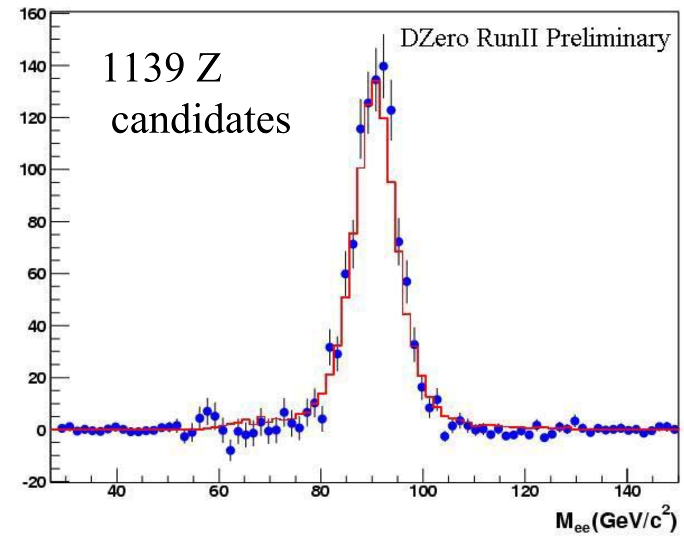
$(Run\ 1: 2.49 \pm 0.02_{stat} \pm 0.08_{sys} \pm 0.09_{lum}\ nb)$

W and Z Cross Sections

- Background-subtracted data (~42/pb) distributions in good agreement with simulation

$$\sigma.B(W \to e\nu) =$$
$$3054 \pm 100_{stat} \pm 86_{sys} \pm 305_{lum}\ pb$$
$$(Run\ 1: 2310 \pm 10_{stat} \pm 50_{sys} \pm 100_{lum}\ pb)$$

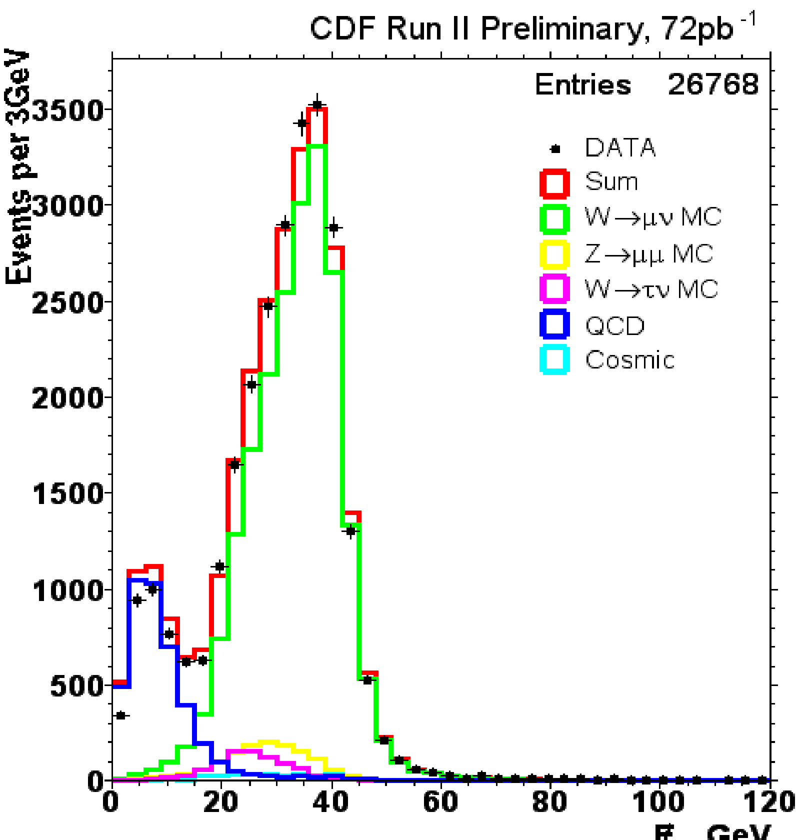


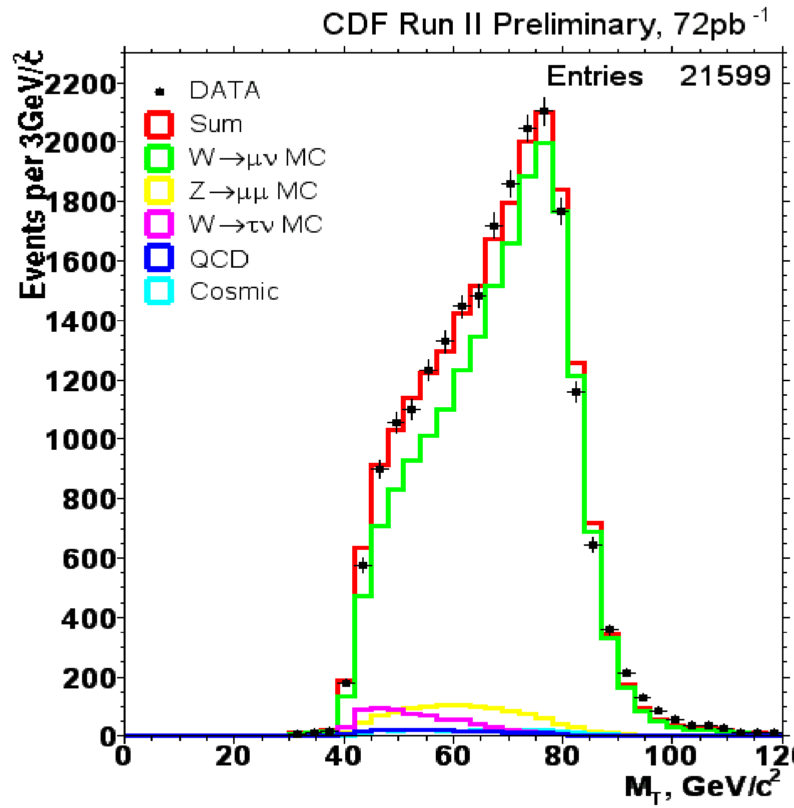


$$\sigma.B(Z \to ee) =$$
$$294 \pm 11_{stat} \pm 8_{sys} \pm 29_{lum}\ pb$$
$$(Run\ 1: 221 \pm 3_{stat} \pm 4_{sys} \pm 10_{lum}\ pb)$$

W Cross Sections

- Dominant uncertainties: luminosity, acceptance (PDFs, detector modelling) and efficiency (for muon channel)





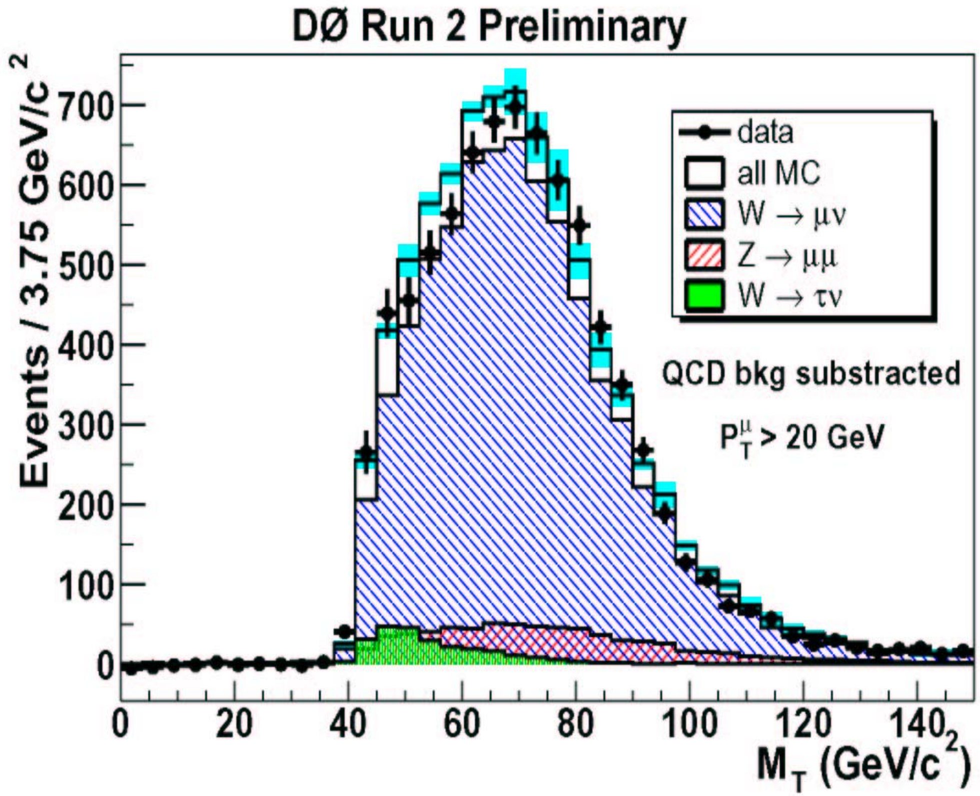
$$\sigma.B(W \to \mu\nu) =$$
$$2.64 \pm 0.02_{stat} \pm 0.12_{sys} \pm 0.16_{lum}\, nb$$
$$(Run\ 1 : 2.21 \pm 0.22\, nb)$$

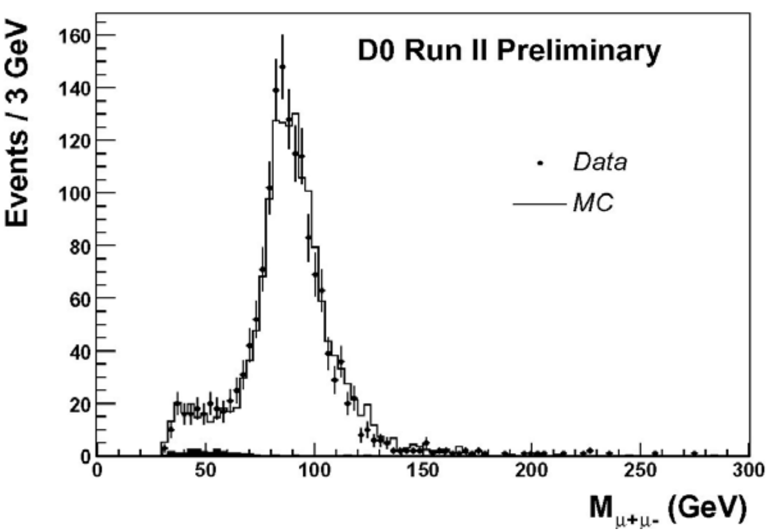
W and Z Cross Sections

- 7352±154 $W \to \mu\nu$ candidates in 17.3/pb of data
  1585 $Z \to \mu\mu$ candidates in 31.8/pb of data

$$\boxed{\begin{array}{l}\sigma.B(Z \to \mu\mu) = \\ 264 \pm 7_{stat} \pm 17_{sys} \pm 26_{lum}\ pb\end{array}}$$

$(Run\ 1{:}178 \pm 22_{stat} \pm 21_{sys} \pm 9_{lum}\ pb)$



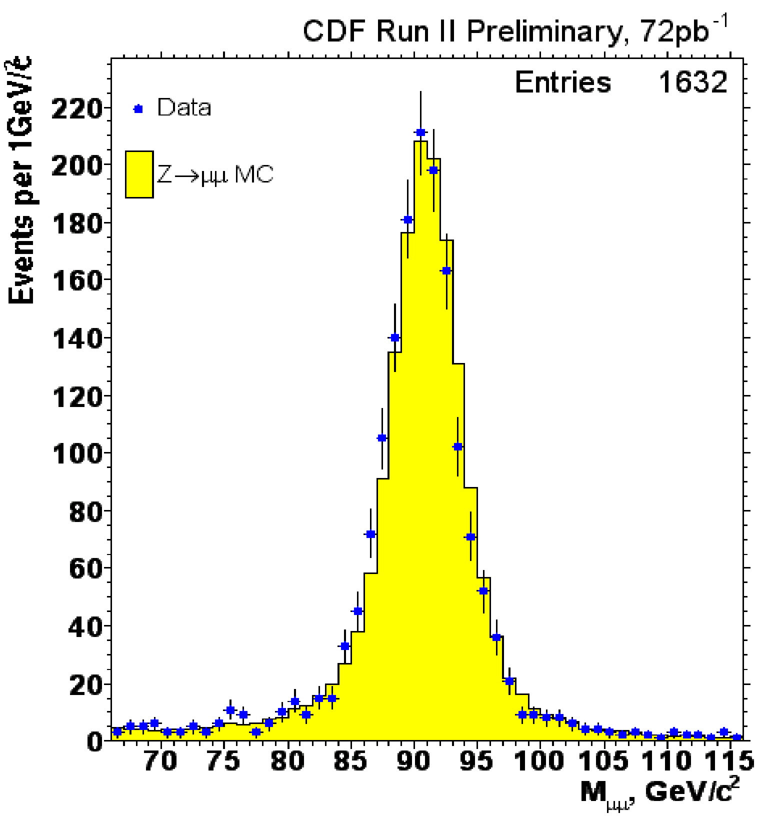


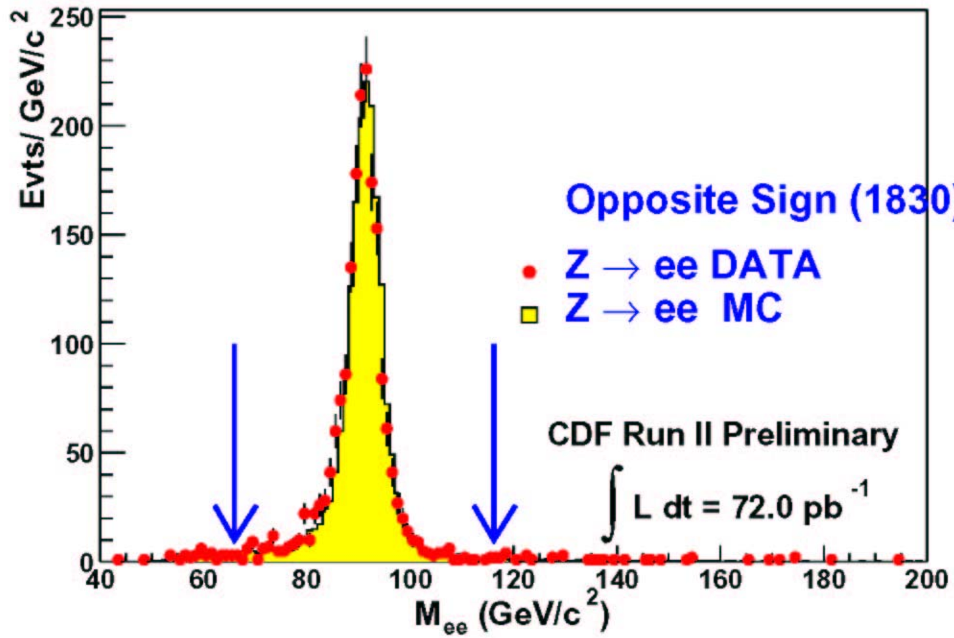
$$\boxed{\begin{array}{l}\sigma.B(W \to \mu\nu) = \\ 3.226 \pm 0.128_{stat} \pm 0.100_{sys} \pm 0.323_{lum}\ nb\end{array}}$$

$(Run\ 1{:}2.09 \pm 0.06_{stat} \pm 0.22_{sys} \pm 0.11_{lum}\ nb)$

Z Cross Sections

- Backgrounds < 1%
- Forward coverage will extend acceptance





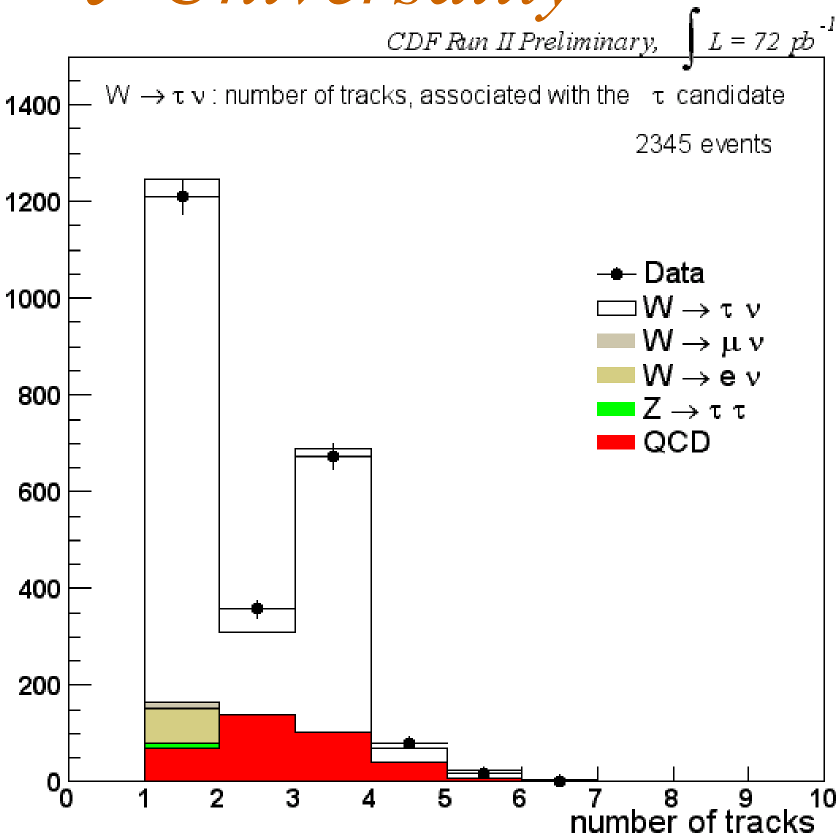
$$\sigma.B(Z \to \mu\mu) = 246 \pm 6_{stat} \pm 12_{sys} \pm 15_{lum}\ pb$$

$$(Run\ 1: 233 \pm 18\ pb)$$

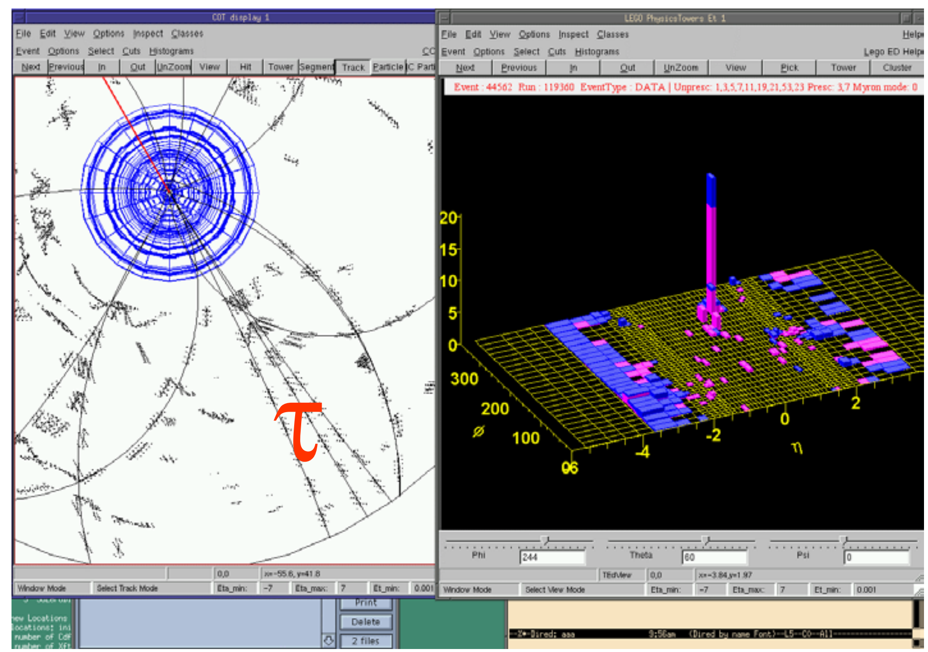
$$\sigma.B(Z \to ee) = 267 \pm 6_{stat} \pm 15_{sys} \pm 16_{lum}\ pb$$

$$(Run\ 1: 231 \pm 6_{stat} \pm 7_{sys} \pm 8_{lum}\ pb)$$

τ Universality



- Clean hadronic W -> τ decays
- Baseline analysis for new physics searches involving τ



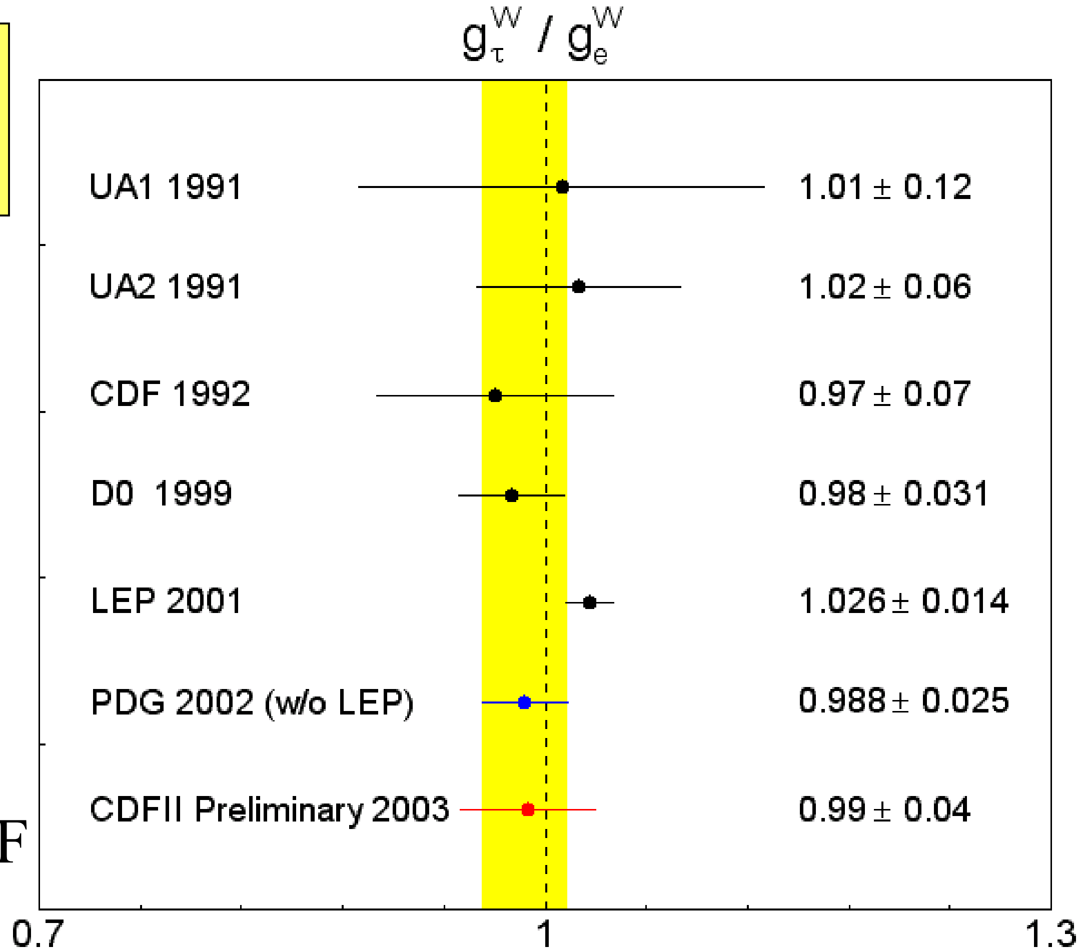
$$\sigma.B(W \rightarrow \tau\nu) =$$
$$2.62 \pm 0.07_{stat} \pm 0.21_{sys} \pm 0.16_{lum}\ nb$$

τ Universality

$$g_\tau / g_e = 0.99 \pm 0.02_{stat} \pm 0.04_{sys}$$

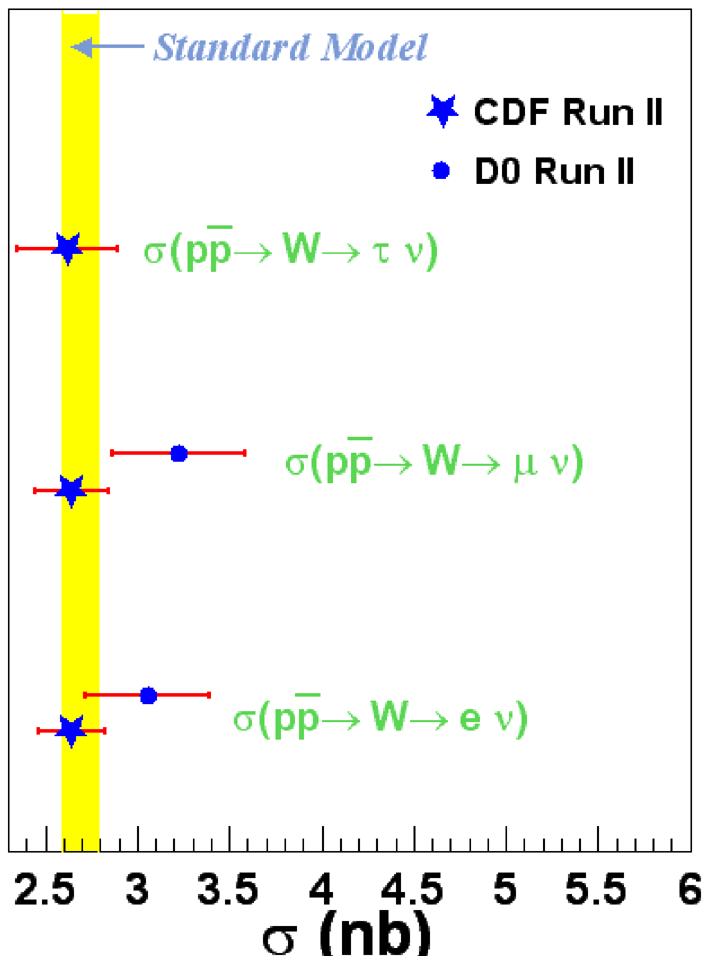
- Uncertainties due to τ acceptance, efficiency, energy calibration and backgrounds contribute about equally.

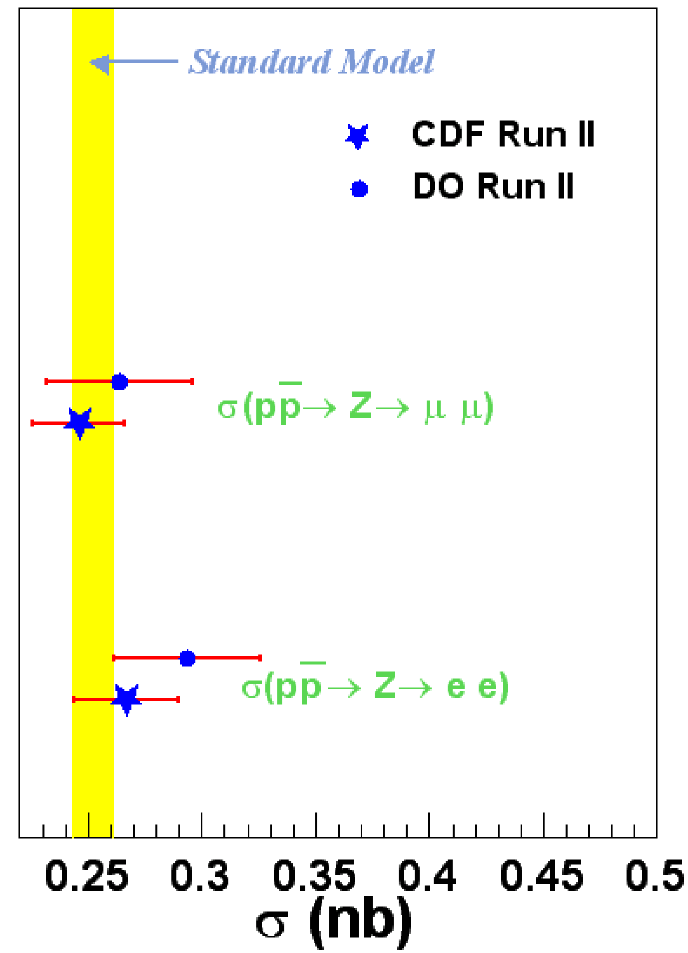
- Uncertainties mostly uncorrelated between CDF and D0.



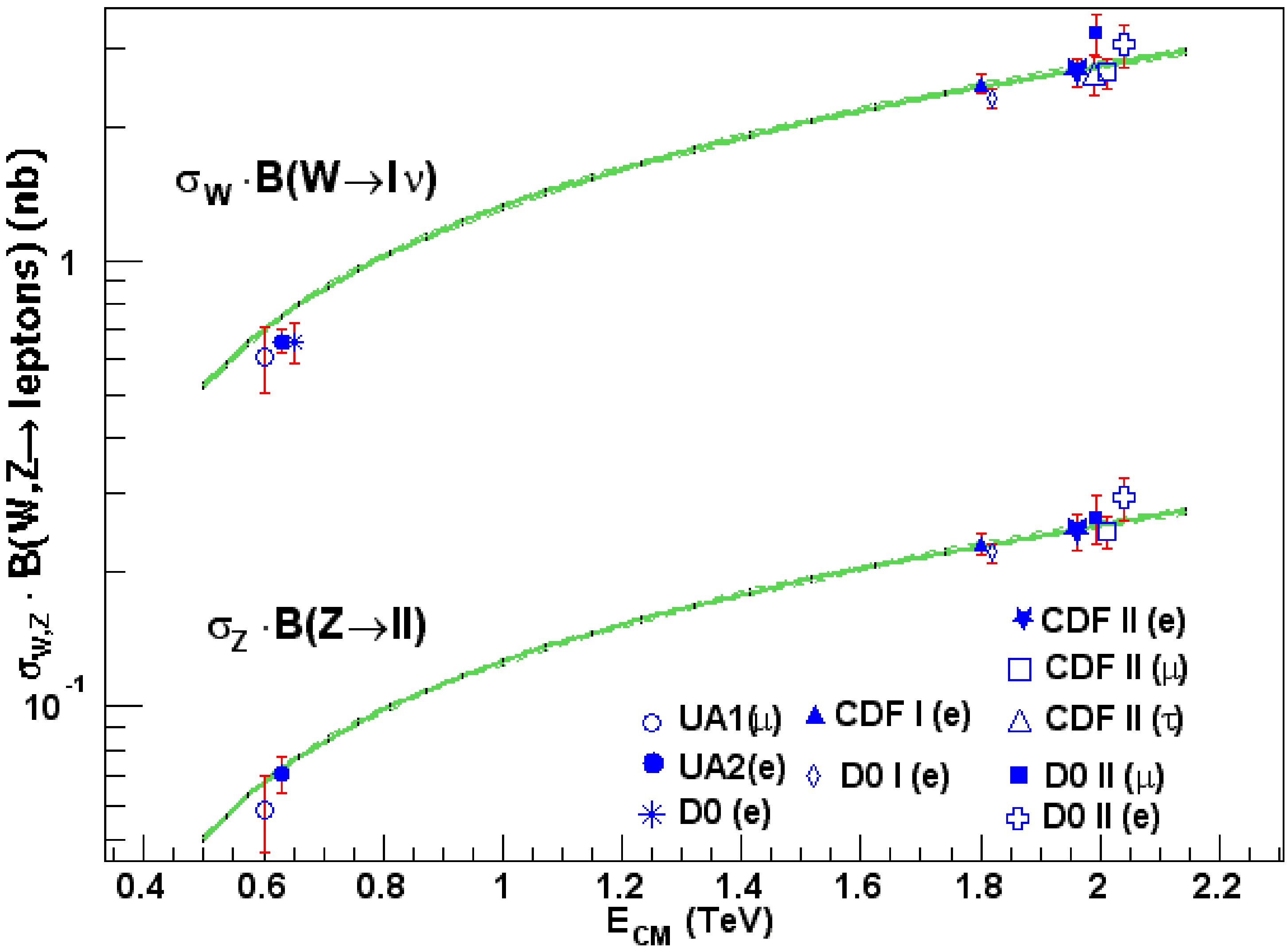
W and Z Cross Sections Summary

- Run 2 measurements consistent with predictions





W and Z Cross Sections Summary



$Br(W \longrightarrow l\ \nu)$ and $\Gamma(W)$

$$R = \frac{\sigma(W) \cdot Br(W \to l\nu)}{\sigma(Z) \cdot Br(Z \to ll)}$$

- Dominant systematics due to detector modelling and backgrounds

CDF

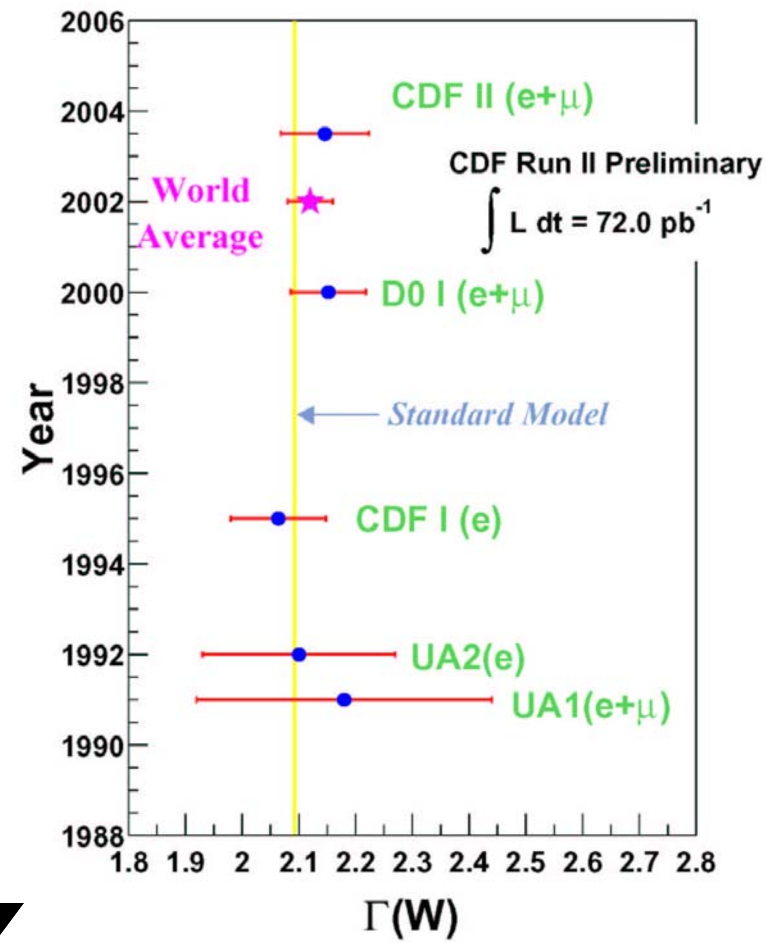
$$R_e = 9.88 \pm 0.24_{stat} \pm 0.47_{sys}$$

$$R_\mu = 10.69 \pm 0.27_{stat} \pm 0.33_{sys}$$

- Run 1 CDF/D0 combined:

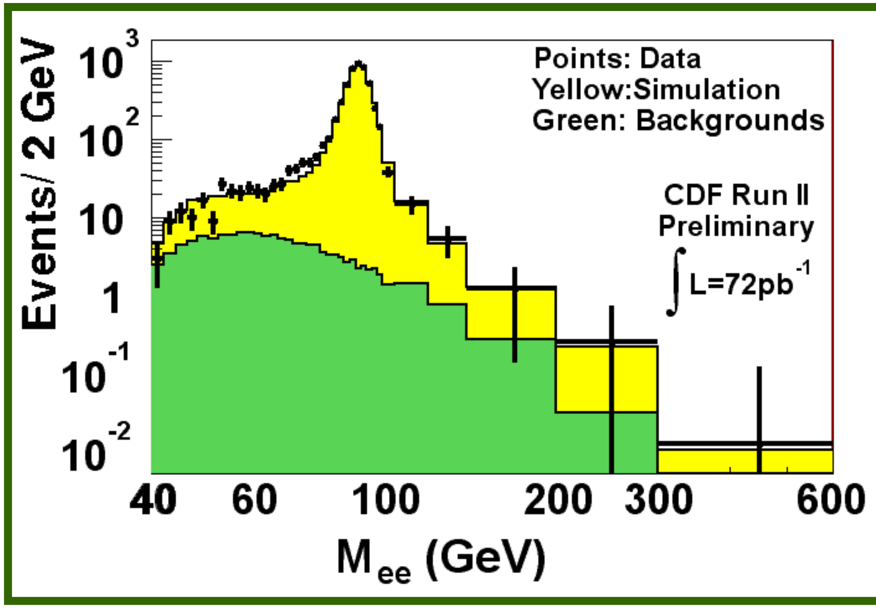
$$R = 10.59 \pm 0.20_{uncorr} \pm 0.11_{corr}$$

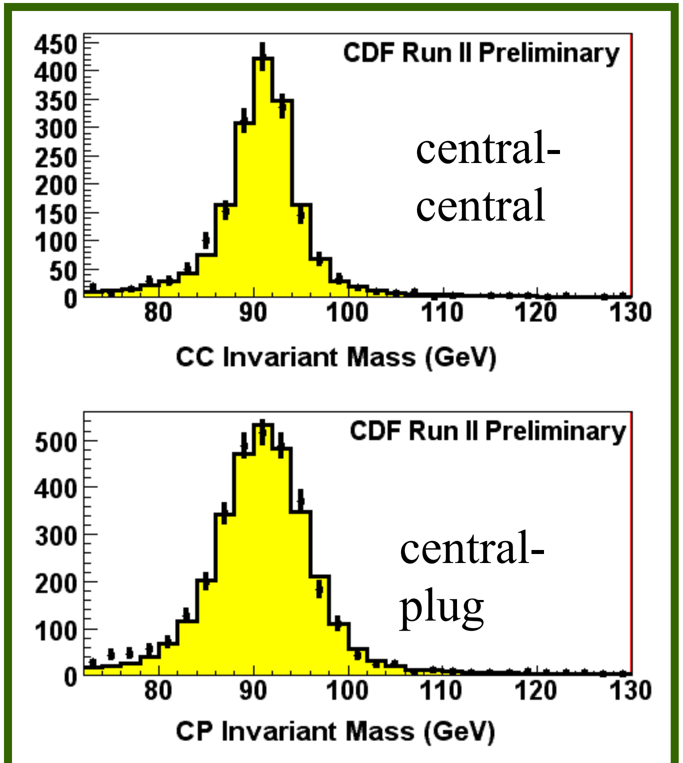
- Extract $\Gamma(W)$ using SM $\Gamma(W \longrightarrow \ell\nu)$



Dielectron Forward-Backward Asymmetry

- Off-pole, high mass A_{FB} unique to Tevatron
- Sensitive to new physics @ 1st order in amplitude, through interference





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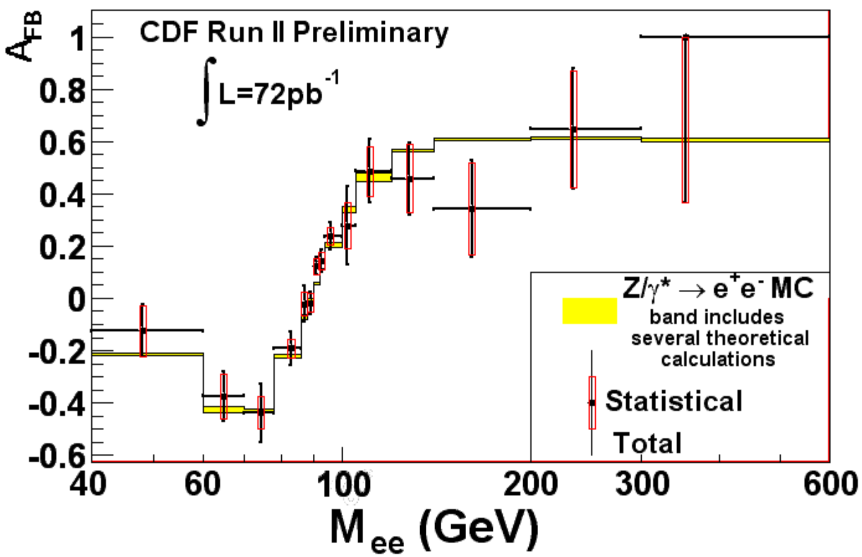
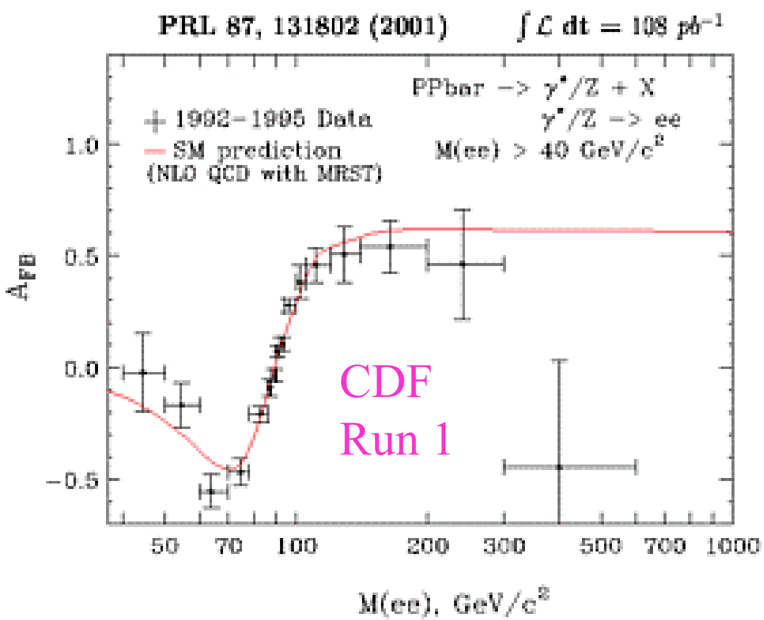
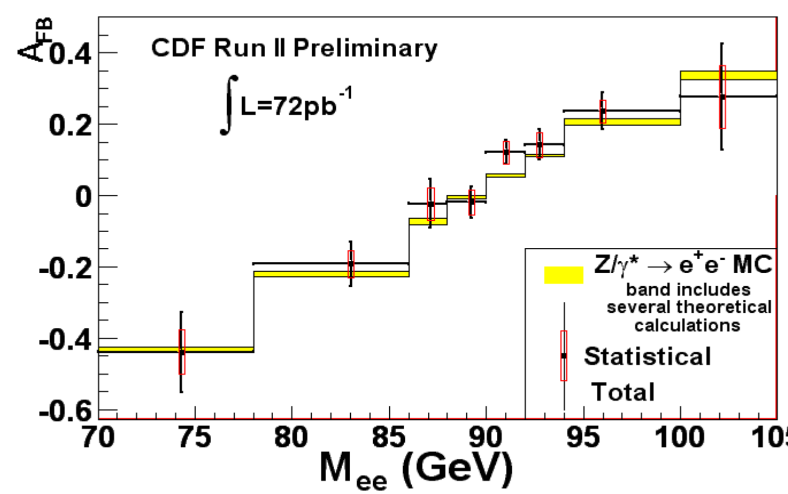
Exploit forward coverage

Dielectron Forward-Backward Asymmetry

- Run 2 measurement consistent with SM prediction, statistics-limited at high mass

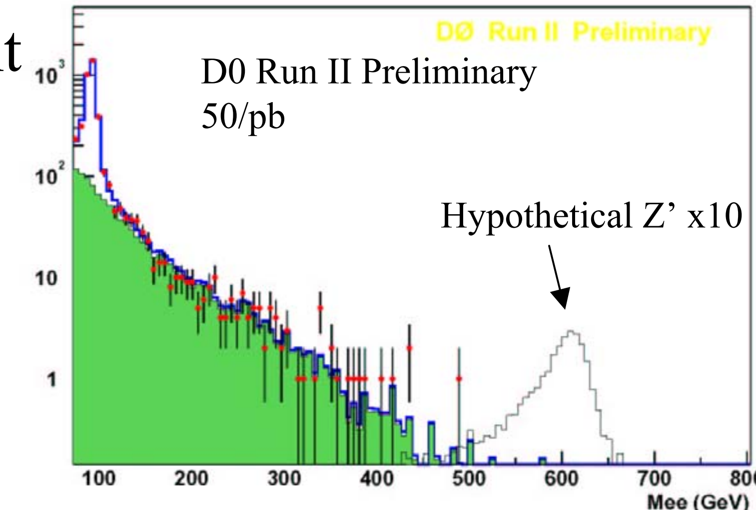


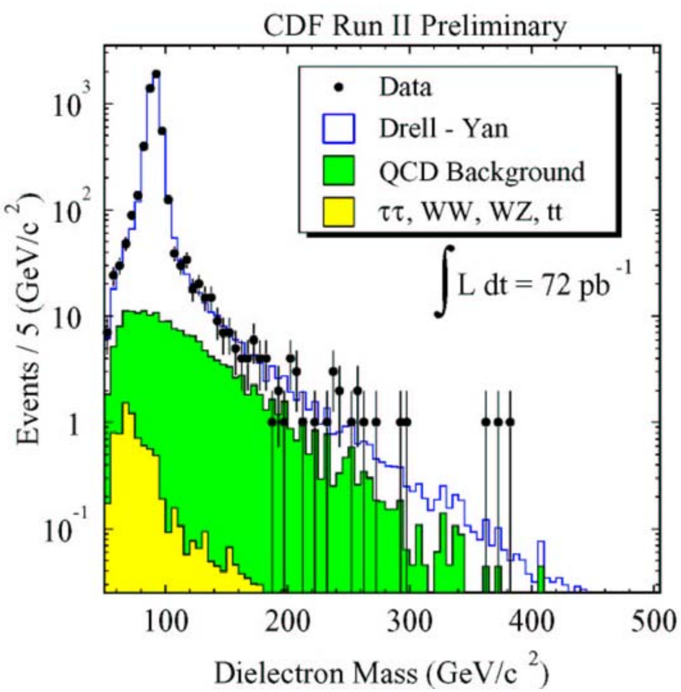


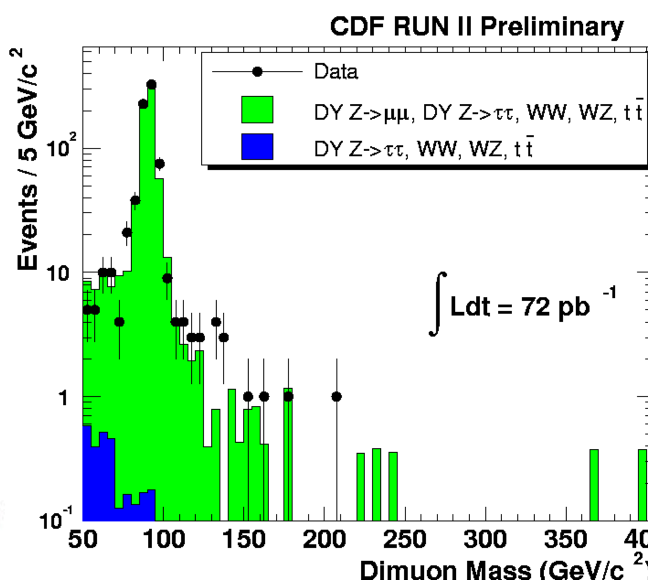


Z' Search using High Mass Drell-Yan

- Dilepton mass distributions consistent with standard model
- Higher c.m.s. energy increases sensitivity





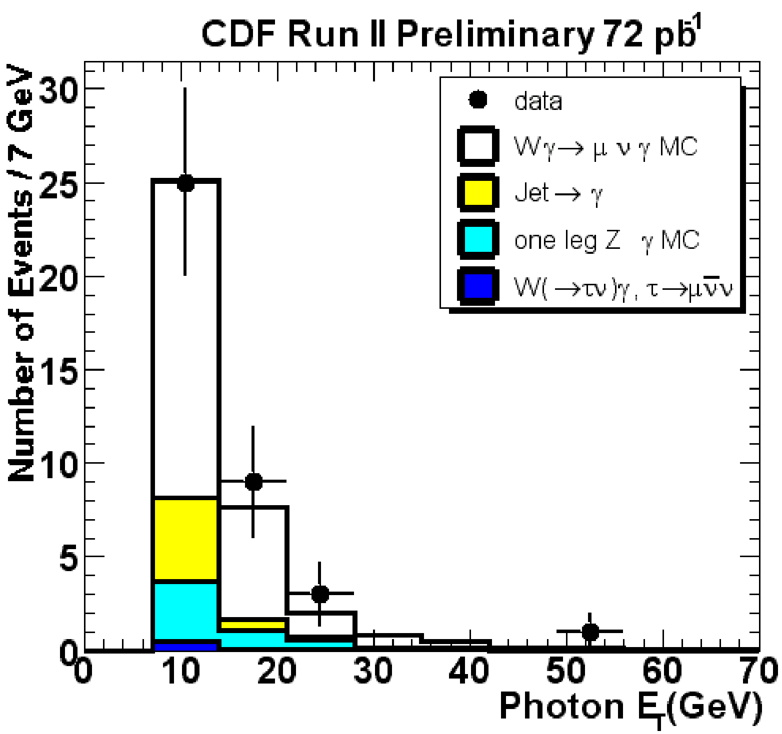


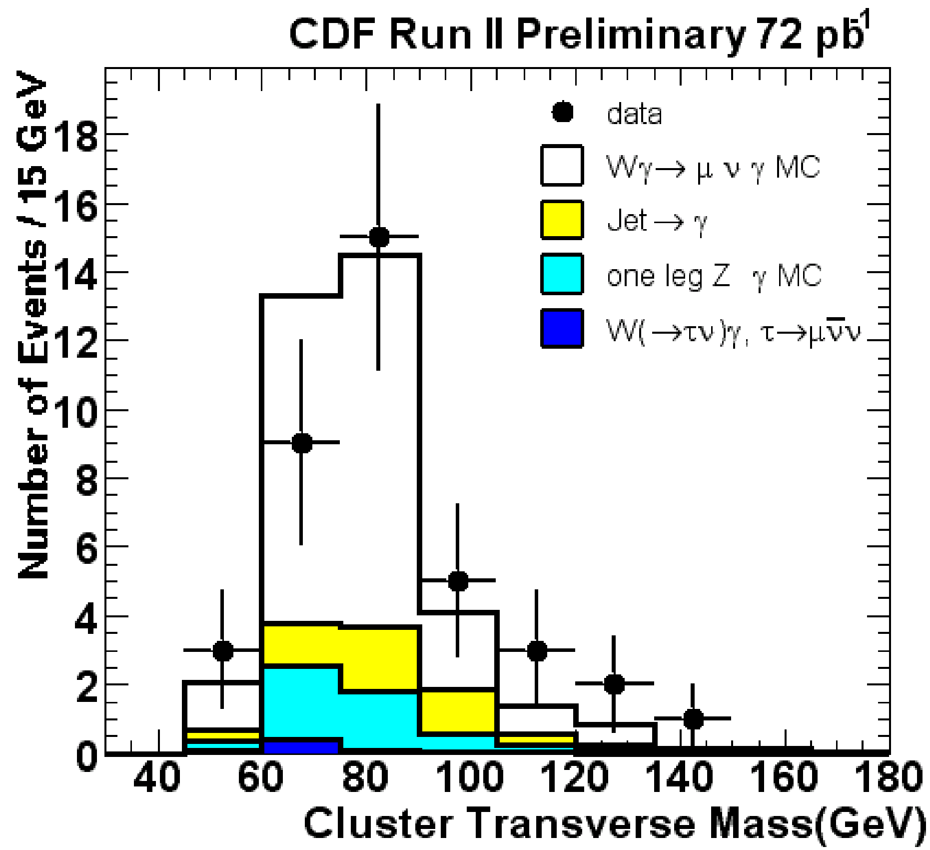
95% CL mass limits (GeV)

	CDF e	D0 e	CDF μ
Run 2	650	620	455
Run 1	640	670	575

$W\gamma \longrightarrow \mu\nu\gamma$

- 38 events observed, with signal expectation of $25.5 \pm 0.6_{stat} \pm 2.3_{sys}$ and estimated background of $11.0 \pm 0.4_{stat} \pm 1.7_{sys}$

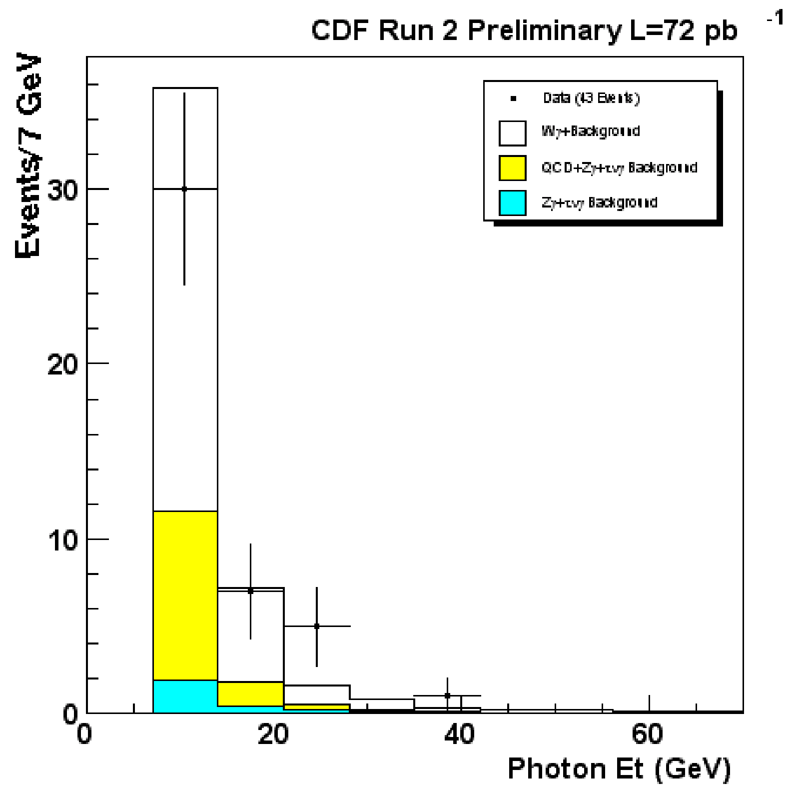


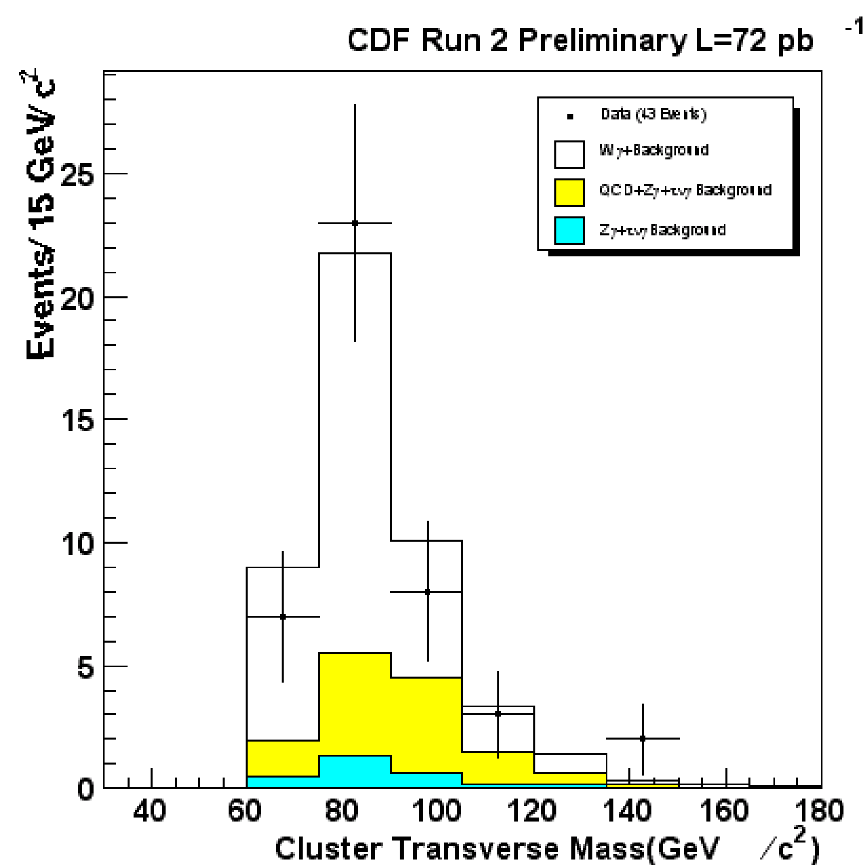


$$\sigma.B(W\gamma \to \mu\nu\gamma) =$$
$$19.8 \pm 4.5_{stat} \pm 2.4_{sys} \pm 1.2_{lum}\ pb$$

$W\gamma \rightarrow e\nu\gamma$

- 43 events observed, with signal expectation of $32.2 \pm 1.3_{stat} \pm 2.5_{sys}$ and estimated background of $14.4 \pm 0.4_{stat} \pm 3.8_{sys}$

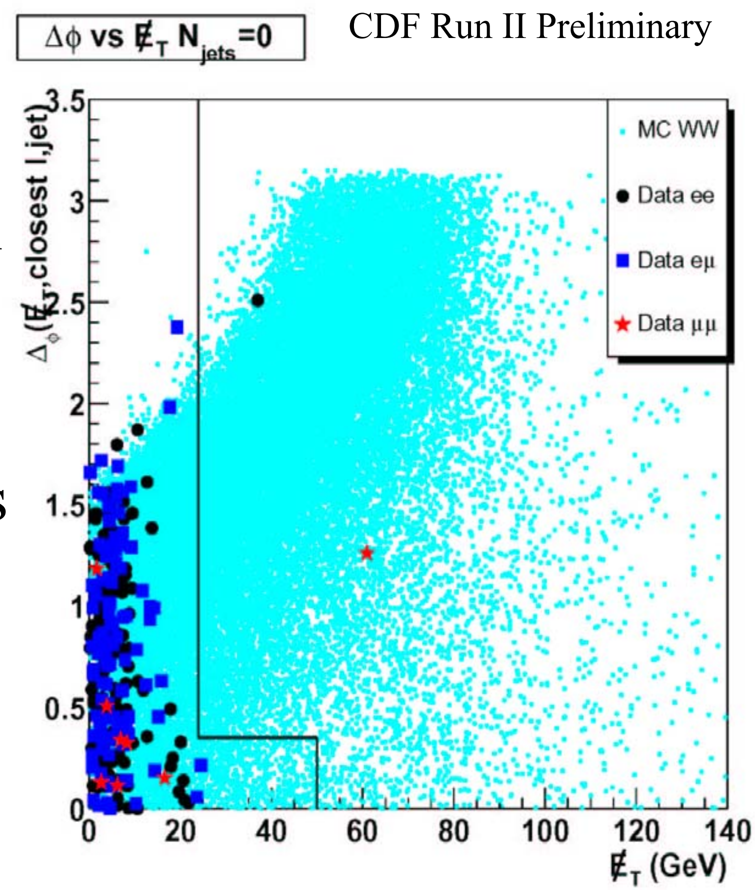




$$\sigma.B(W\gamma \rightarrow e\nu\gamma) =$$
$$17.2 \pm 3.8_{stat} \pm 2.8_{sys} \pm 1.0_{lum}\ pb$$

Search for WW Production

- Establish SM WW/WZ signals as precursor to SM Higgs search
- CDF Run 2: dilepton + $\not{E}_T$ signature yields 2 candidates; expected signal of 2.79 ± 0.62 events and background of 1.53 ± 0.64 events



- Combined D0 Run 1 95% CL limits from all WWV channels ($\Lambda = 2$ TeV):

$$-0.25 < \Delta k < 0.39 \;\; (\lambda = 0)$$

$$-0.18 < \lambda < 0.19 \;\; (\Delta k = 0)$$

W mass and width

- Run 1 results from fits to transverse mass and lepton p_T distributions:

	CDF	D0
M_W	80.433 ± 0.079 GeV	80.483 ± 0.084 GeV
Γ_W	2.05 ± 0.13 GeV	$2.231^{+0.175}_{-0.170}$ GeV

W mass and width

- Tevatron (CDF & D0) averages:
  - M_W = 80.456 ± 0.059 GeV (19 MeV correlated uncertainty)
  - Γ_W = 2.115 ± 0.105 GeV (26 MeV correlated uncertainty)
  - correlation due to PDFs, QED radiative corrections and W width/mass inputs

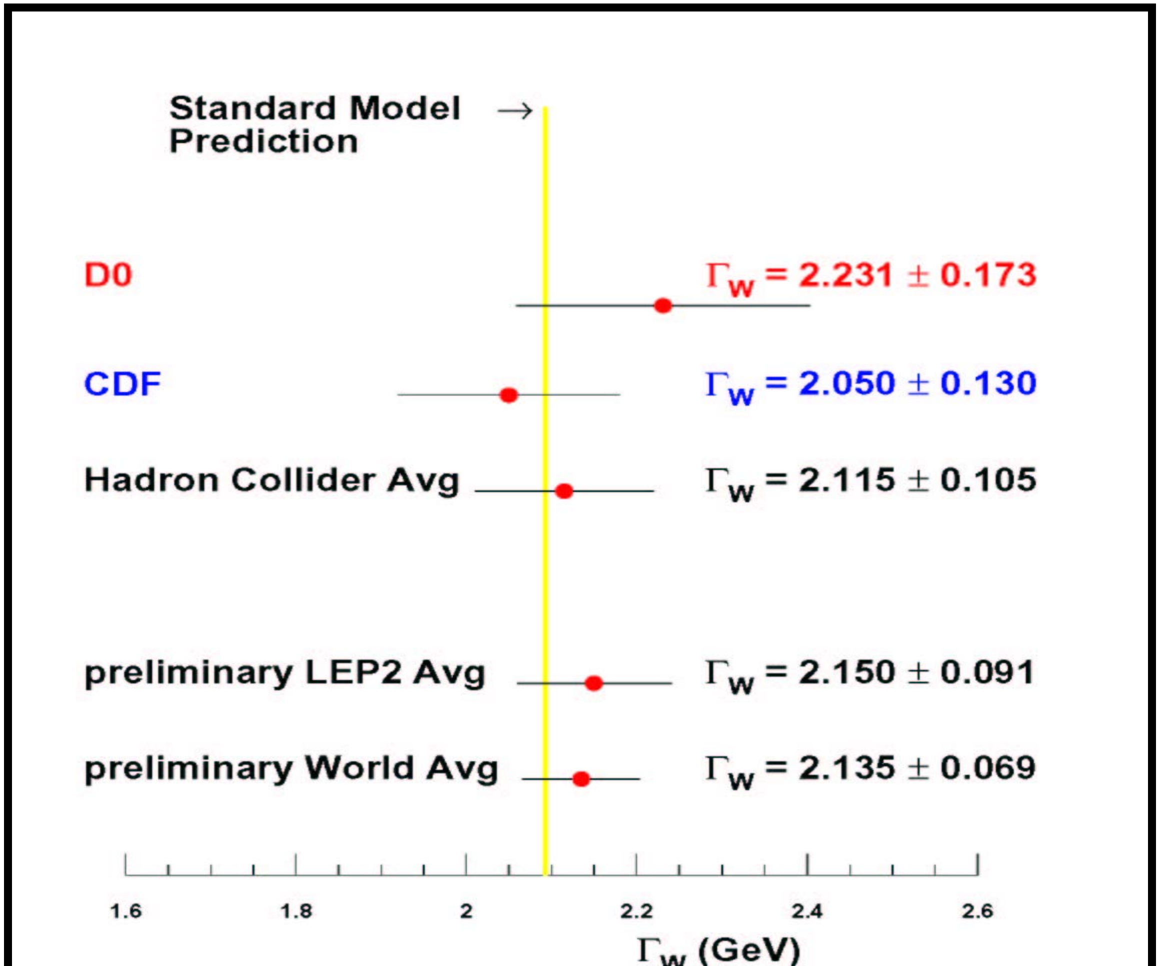
- Joint M_W-Γ_W combination (no external mass or width information):
  - M_W = 80.452 ± 0.059 GeV
  - Γ_W = 2.102 ± 0.106 GeV
  - correlation coefficient = -0.17

- $\Gamma(W\text{->}\ell\nu) = \Gamma_W$. Br $(W\text{->}\ell\nu)$ = 224 ± 13 MeV

  (SM: $\Gamma(W\text{->}\ell\nu) =$ 227.1 ± 0.6 MeV)

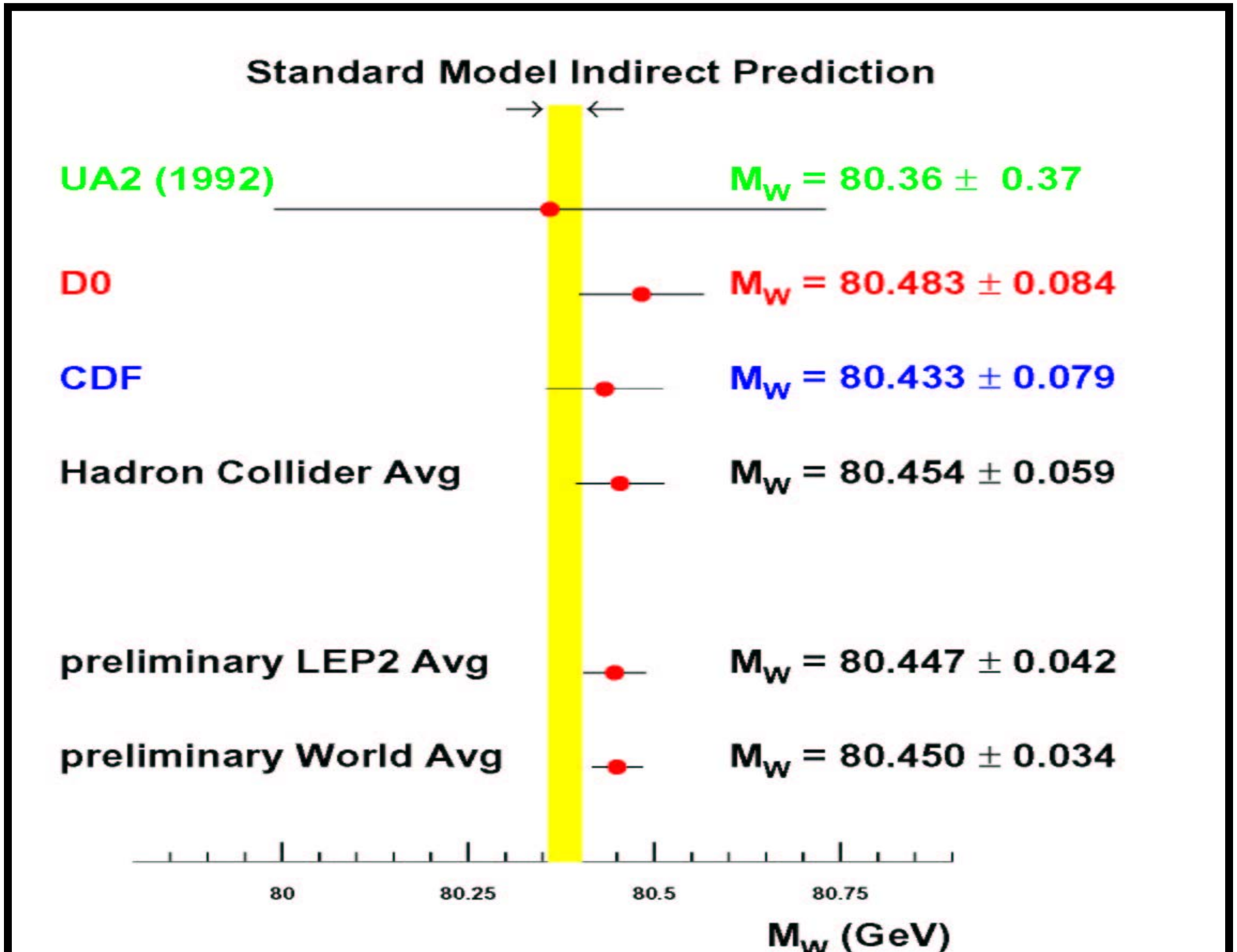
W mass and width

- Γ_W is consistent with SM



W mass and width

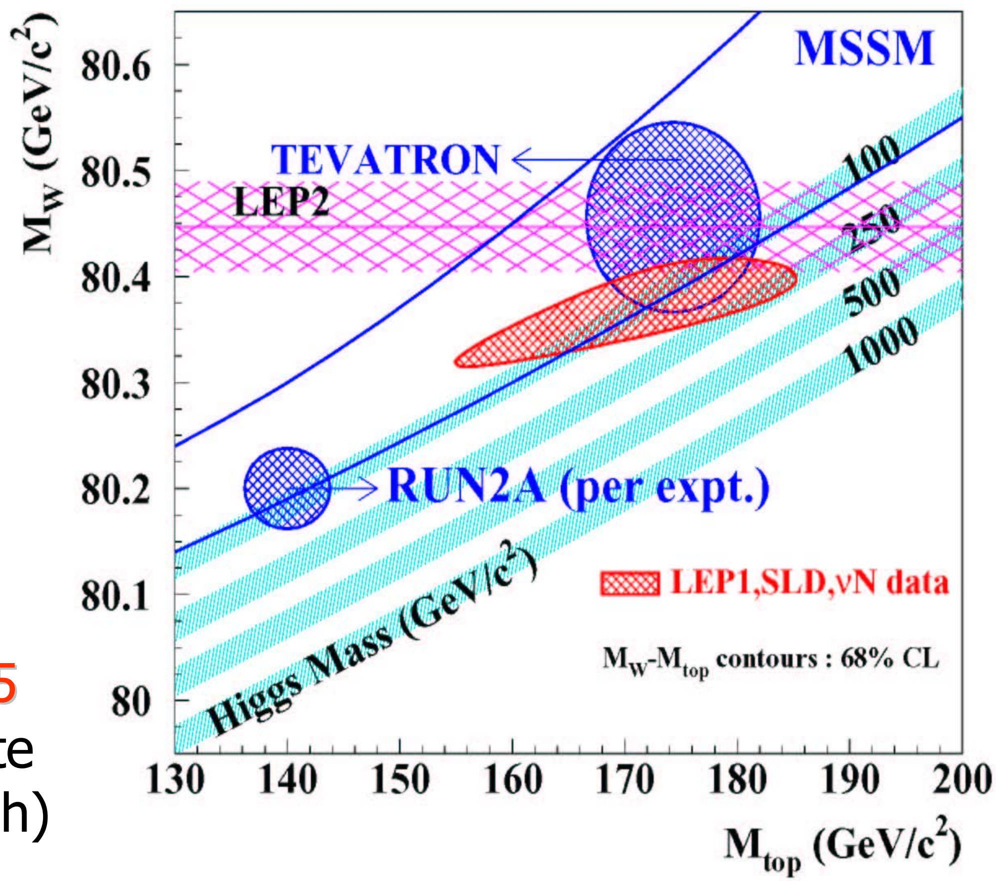
- M_W is ~1.8σ high relative to SM, favors low Higgs mass



Higgs Constraint

- Current SM Higgs fit: $m_H = 81^{+51}_{-33}$ GeV ($\Delta\log(mH/GeV)=0.23$) (hep-ex/0212036)

- Assuming Run 2A (2/fb/expt) yields
  $\Delta M_W = 40$ MeV
  $\Delta M_{top} = 3$ GeV
  per experiment, and
  $\Delta M_W = 30$ MeV
  $\Delta M_{top} = 2.5$ GeV
  combined



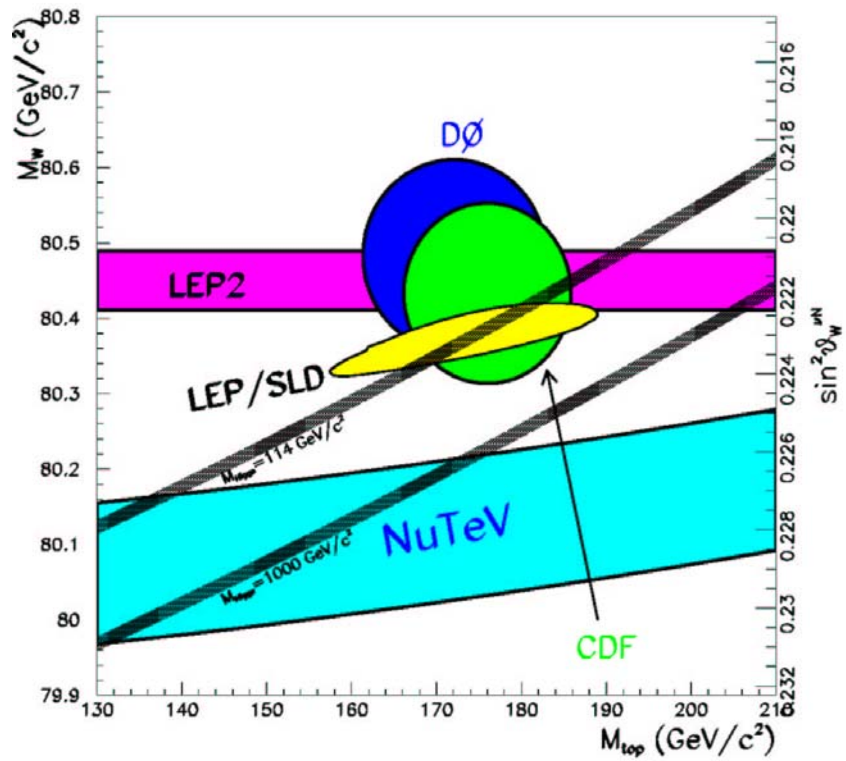
- Expect $\Delta\log(mH/GeV)=0.15$ (Δm_{top} and $\Delta\alpha(M_Z)$ contribute equivalent ΔM_W=15 MeV each)

$Sin^2\theta_W$ from NuTeV

- Using sign-selected neutrino beam for νN scattering, NuTeV measured
  $\sin^2\theta_W = 0.2277 \pm 0.0013_{stat} \pm 0.0009_{syst}$
  with small residual dependence on M_{top} and M_H
  (G. P. Zeller et al, PRL 88, 091802)

- Approx. 3σ different from SM fit:
  $\sin^2\theta_W = 0.2227 \pm 0.0004$

- Possible SM explanations:
  - isospin violation in nucleon
  - asymmetric strange sea
  - nuclear shadowing effects
  - NLO QCD effects
  - .
  - .



$Sin^2\theta_W$ from NuTeV

- NuTeV analyses of their data for possible SM explanations (hep-ex/0205080, hep-ex/0203004 and references therein) do not support these hypotheses:
  - dimuon data exclude strange sea asymmetry as cause
  - estimates of isospin-breaking and NLO QCD too small
  - nuclear shadowing disfavored by separate neutrino, antineutrino measurements and high Q^2 of data
- Non-SM hypotheses:
  - new contact interaction ($\Lambda \sim 4$ TeV)
  - extra U(1) gauge boson ($M_{Z'} \sim 1 - 1.5$ TeV)

- Tevatron Run 2 sensitivity in related channels extends to these energies: may lead to interesting manifestations

Future Tevatron Prospects

- Scaling of ΔM_W and $\Delta\Gamma_W$ errors with integrated luminosity:
  - during 1987-1995 running period, integrated luminosity per collider experiment increased from 4 $pb^{-1} \rightarrow$ 20 $pb^{-1} \rightarrow$ 110 pb^{-1}
  - ΔM_W reduced correspondingly from ~400 MeV $\rightarrow$ 150 MeV $\rightarrow$ 60 MeV, following $1/\sqrt{L}$ scaling
  - systematics constrained with collider data, e.g. exploiting forward coverage to constrain PDF uncertainty
  - continuation of this trend could lead to $\Delta M_W \sim 15$ MeV, $\Delta\Gamma_W \sim 25$ MeV with 2 fb^{-1}

Future Prospects

- Precision measurement of Br ($W \longrightarrow \ell\nu$):
  - dominant experimental systematics in ratio of W and Z cross sections - acceptance ratio, detector response, backgrounds can be constrained with collider data
  - total fractional uncertainty *O*(1%) may be achieved (Run 1 fractional uncertainty due to electroweak radiative corrections was 1%)
  - combining Γ_W and Br ($W \longrightarrow \ell\nu$), $\Gamma(W \longrightarrow \ell\nu)$ may be measured with a precision of a few %

Future Prospects

- Electroweak physics at high mass:
  - diboson production (sensitive to anomalous couplings and form factor scale Λ)
  - Drell-Yan ($\gamma/Z/W$) cross sections and asymmetries

  extend sensitivity to new physics to energies approaching 1 TeV

- Precise measurements of differential cross sections (boson p_T, rapidity and polarization) provide unique information on W and Z production dynamics

Summary

- Very successful electroweak physics program at the Tevatron Run 1 is complete
- Run 2 is well underway – already producing electroweak physics results of comparable precision to Run 1
- No show-stoppers on the way to exploiting 2 fb^{-1} (and more!) of Run 2 data